APPENDIX E | ATTACHED GARAGE ANALYSIS EQUATIONS

Our approach for assessing the rough magnitude of additional potential benefits that may result from Clean Air Act Amendment (CAAA)-related reductions of in-garage benzene emissions in 2020 involved three steps: first, we assessed the percent reduction in total emissions occurring within attached garages due to the CAAA in 2020; second, we applied the percent reduction to an estimate of average benzene exposure attributable to attached garages; third, we calculated the annual number of avoided cases of leukemia in the Houston area in 2020 that would be expected based on the CAAA-related reduction in attached garage-related exposures. We describe these steps in greater detail below.

Step 1

We first calculated the percent reduction in total emissions occurring within attached garages due to the CAAA in 2020. Total emissions include emissions from both non-road and on-road source categories. We calculated the difference using the following equation:

$$R_g = (E_{g\ \textit{Without-CAAA}} - E_{g\ \textit{With-CAAA}})/E_{g\ \textit{Without-CAAA}}$$

Where:

> R_g = percent reduction in emissions occurring within attached garages due to the CAAA;
>
> $E_{g\ \textit{Without-CAAA}}$= total emissions occurring within attached garages under the *Without-CAAA* scenario in tons/year ($Eg_{\text{non-road}\ \textit{Without}} + Eg_{\text{on-road}\ \textit{Without}}$); and
>
> $E_{g\ \textit{With-CAAA}}$ = total emissions occurring within attached garages under the *With-CAAA* scenario in tons/year ($E_{g\ \text{non-road}\ \textit{With}} + E_{g\ \text{on-road}\ \textit{With}}$).

We employed different approaches for estimating the non-road and on-road component of emissions occurring within attached garages under each of the scenarios, because of differences in the available emissions data for these two source categories. We describe the two approaches in detail below.

Non-road Emissions Occurring Within Attached Garages

In order to calculate the non-road emissions occurring within attached garages under each of the two scenarios, we first identified only those non-road vehicles or equipment that we would expect to be kept in a garage. These included all residential lawn and gardening equipment as well as recreational non-road vehicles.[1] We then took estimates of benzene emissions in 2020 in tons per year for each of the selected non-road vehicles and equipment and split the emissions estimates into emission categories (i.e., exhaust, evaporative, refilling).[2] For example, we used the following equation to calculate the evaporative fraction of total emissions from a particular non-road source under the *Without-CAAA* scenario:

$$E_{\text{evap NR } \textit{Without}} = f_{\text{evap NR } \textit{Without}} \times E_{\text{NR } \textit{Without}}$$

Where:

$E_{\text{evap NR } \textit{Without}}$ = the non-road emissions that are evaporative under the *Without-CAAA* scenario in tons/year;

$f_{\text{evap NR } \textit{Without}}$ = the fraction of non-road emissions that are evaporative under the *Without-CAAA* scenario; and

$E_{\text{NR } \textit{Without}}$ = the total non-road emissions under the *Without-CAAA* scenario in tons/year.

We repeated this process for each combination of emissions category (evaporative, exhaust, refilling), and scenario (*With-CAAA*, *Without-CAAA*).

Next, we applied to each category a factor describing the fraction of those emissions expected to occur within an attached garage. For each category, we employed a range of percentages for each fraction, using values reported in Appendix 3A of the Regulatory Impact Analysis (RIA) for the Mobile Source Air Toxics Rule (MSAT) (USEPA, 2007; hereafter, the “MSAT RIA”). Table 2 provides the ranges of percentages we used for each of the emissions categories. We used theses values in the following equation to estimate the total non-road emissions expected to occur with in an attached garage:

$$Eg_{\text{NR } \textit{Without}} = (E_{\text{evap NR } \textit{Without}} \times f_{g \text{ evap}}) + (E_{\text{exh NR } \textit{Without}} \times f_{g \text{ exh}}) + (E_{\text{refill NR } \textit{Without}} \times f_{g \text{ refill}})$$

Where:

$E_{g \text{ NR } \textit{Without}}$ = total non-road emissions occurring within attached garages under the *Without-CAAA* scenario in tons/year;

$E_{\text{evap NR } \textit{Without}}$ = the non-road emissions that are evaporative under the *Without-CAAA* scenario in tons/year;

[1] If a particular type of non-road vehicles had more than one variety, we took an average across all varieties. For instance, we took an average of the emissions from 2-stroke rotary tillers and 4-stroke rotary tillers to estimate the in-garage emissions from an average rotary tiller.

[2] These data were provided by E.H Pechan and Associates (Pechan, 2008a).

$f_{g\ evap}$ = the fraction of evaporative emissions that occur within an attached garage;

$E_{exh\ NR\ \mathit{Without}}$ = the non-road emissions that are exhaust-related under the *Without-CAAA* scenario in tons/year;

$f_{g\ exh}$ = the fraction of exhaust-related emissions that occur within an attached garage;

$E_{refill\ NR\ \mathit{Without}}$ = the non-road emissions that are refilling-related under the *Without-CAAA* scenario in tons/year; and

$f_{g\ refill}$ = the fraction of refilling-related emissions that occur within an attached garage.

We repeated this process for the 2020 *With-CAAA* scenario. We then summed across all non-road vehicles and equipment to estimate the total emissions from this source category occurring within an attached garage under each scenario.

TABLE 2: ASSUMED FRACTIONS OF EMISSIONS FROM NON-ROAD GASOLINE EQUIPMENT AND VEHICLES OCCURRING WITHIN AN ATTACHED GARAGE

EMISSIONS CATEGORY	RANGE OF VALUES
Exhaust	0 – 2 percent
Evaporative	90 – 100 percent
Refilling-Related	25 – 75 percent
Source: Appendix 3A of the MSAT RIA, page 3-133, footnote u.	

On-road Emissions Occurring Within Attached Garages

The available data for on-road emissions included the annual benzene emissions factors under the 2020 *With-* and *Without*-CAAA scenarios for emissions that are expected to occur within a garage. Pechan generated these factors using MOBILE6.2 (Pechan, 2008b). We focused on emissions related to light-duty gasoline vehicles (LDGV) and light-duty gasoline trucks with a loaded vehicle weight of 3,750 pounds and below (LDGT1). These emissions factors included idle (grams/min), start up (grams/start), hot soak (grams/trip end), diurnal (grams/day), resting loss (grams/day), and idle resting loss (grams/min). The emission factors were on a per vehicle basis. In order to estimate the total 2020 on-road emissions in tons per year that occur within an attached garage, we made a number of assumptions.

We first converted all of the emissions factors into units of tons/year/vehicle. This process differed depending on the specific emission factor. We assumed that on average, each vehicle would make two trips originating at the home and two trips ending at the home.[3] We also assumed that each vehicle would idle for five minutes for every trip start and end at the home.

We then summed all of the emissions for each of the two vehicle types (LDGV and LDGT1) and took an average across them. We then estimated the total in-garage on-road emissions in the Houston area in 2020 by multiplying the average emissions in tons/year/vehicle by an estimate of the average number of vehicles per garage as well as an estimate of the number of attached garages in the Houston area.[4]

Step 2

Once we calculated the percent reduction in total emissions occurring within attached garages due to the CAAA in 2020, we applied it to an estimate of average indoor benzene exposure attributable to attached garages reported in Appendix 3A of the MSAT RIA to calculate an expected attached-garage related exposure reduction, using the following equation:[5]

$$ER_g = R_g \times E_g$$

Where:

> ER_g = average attached garage-related indoor benzene exposure reduction due to the CAAA in $\mu g/m^3$;
>
> R_g = percent reduction in emissions occurring within attached garages due to the CAAA in 2020;
>
> E_g = average indoor benzene exposure estimate attributable to attached garages (1.2 $\mu g/m^3$; Table 3A-1, USEPA, 2007).[6, 7]

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[3] This assumption was based on an estimate of average number of trips per person per day from the National Household Travel Survey (http://nhts.ornl.gov/).

[4] We estimated the average number of vehicles per household from an estimate of the total number of households in the US and the total number of vehicles in the US from the US Energy Information Administration website (http://www.eia.doe.gov/emeu/rtecs/nhts_survey/2001/). The number of attached garages in the Houston area was estimated by first dividing the total population of Harris, Galveston, and Brazoria counties by the average number of people per household in the Houston area (http://www.hellohouston.com/Census.Cfm) to calculate the total number of households. We then multiplied this by the fraction of households in the West South Central Census Region with attached garages from the Residential Energy Consumption Surveys (http://www.eia.doe.gov/emeu/recs/recs2001/detail_tables.html).

[5] The estimate of average indoor benzene exposure attributable to attached garages from the MSAT RIA incorporates an estimate of the fraction of the national population living in homes with attached garages (34.7 percent) from the Residential Energy Consumption Survey (RECS). We found that the estimate for the West South Central Census Region (which includes Texas) was similar. Therefore, we did not make any adjustments to the exposure estimate.

[6] We selected the estimate from Table 3A-1 of the MSAT RIA that was based on all studies except those conducted in Alaska due to a number of differences expected in the attached garage-related exposures between Alaska and Houston. For instance, the fuel in Alaska has atypically high benzene levels, the housing characteristics differ between these two locations, there could potentially be different types of vehicles and equipment found within garages in these locations, and cold starts likely contribute to benzene exposures in Alaska, whereas this would not be a factor in the Houston area.

This approach makes the conservative assumption that the percent reduction in in-garage emissions of benzene will result in an equivalent percent reduction in the component of indoor benzene exposure contributed by the attached garage.

Step 3

In the final step, we calculated the annual number of avoided cases of leukemia in the Houston area in 2020 that would be expected based on the CAAA-related reduction in attached garage-related benzene exposures, using the following equation:

$$\text{Annual Avoided Cases in 2020} = (ER_g \times IUR \times P)/LT$$

Where:

ER_g = average garage-related exposure reduction due to the CAAA in $\mu g/m^3$;

IUR = range of Inhalation Unit Risks for benzene in $(\mu g/m^3)^{-1}$;

P = total population in the Houston case study area; and

LT = lifetime, 70 years.

In this step, we multiply the exposure to the entire population in the Houston area because this exposure estimates represents a weighted average value across the population (see footnote 6).

REFERENCES

E.H. Pechan and Associates (2008a). *Nonroad Evaporative Fraction for IEcs.xls* [electronic file]. Transmitted to Henry Roman from Kirstin Thesing on January 25, 2008.

E.H. Pechan and Associates (2008b). *Garage_Benzene_Reducs_2020.xls* [electronic file]. Transmitted to Henry Roman and Tyra Walsh from Maureen Mullen on January 24, 2008.

U.S. EPA. (2007). Control of Hazardous Air Pollutants from Mobile Sources: Regulatory Impact Analysis. Office of Transportation and Air Quality. EPA420-R-07-002.

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[7] This value represents a weighted average exposure across the population. It was calculated by multiplying the average indoor benzene concentration attributable to an attached garage by the fraction of the population living in a home with an attached garage and the time spent in a home with an attached garage.